

Modeling Acute Health Effects of Astronauts from Exposure to Large Solar Particle Events

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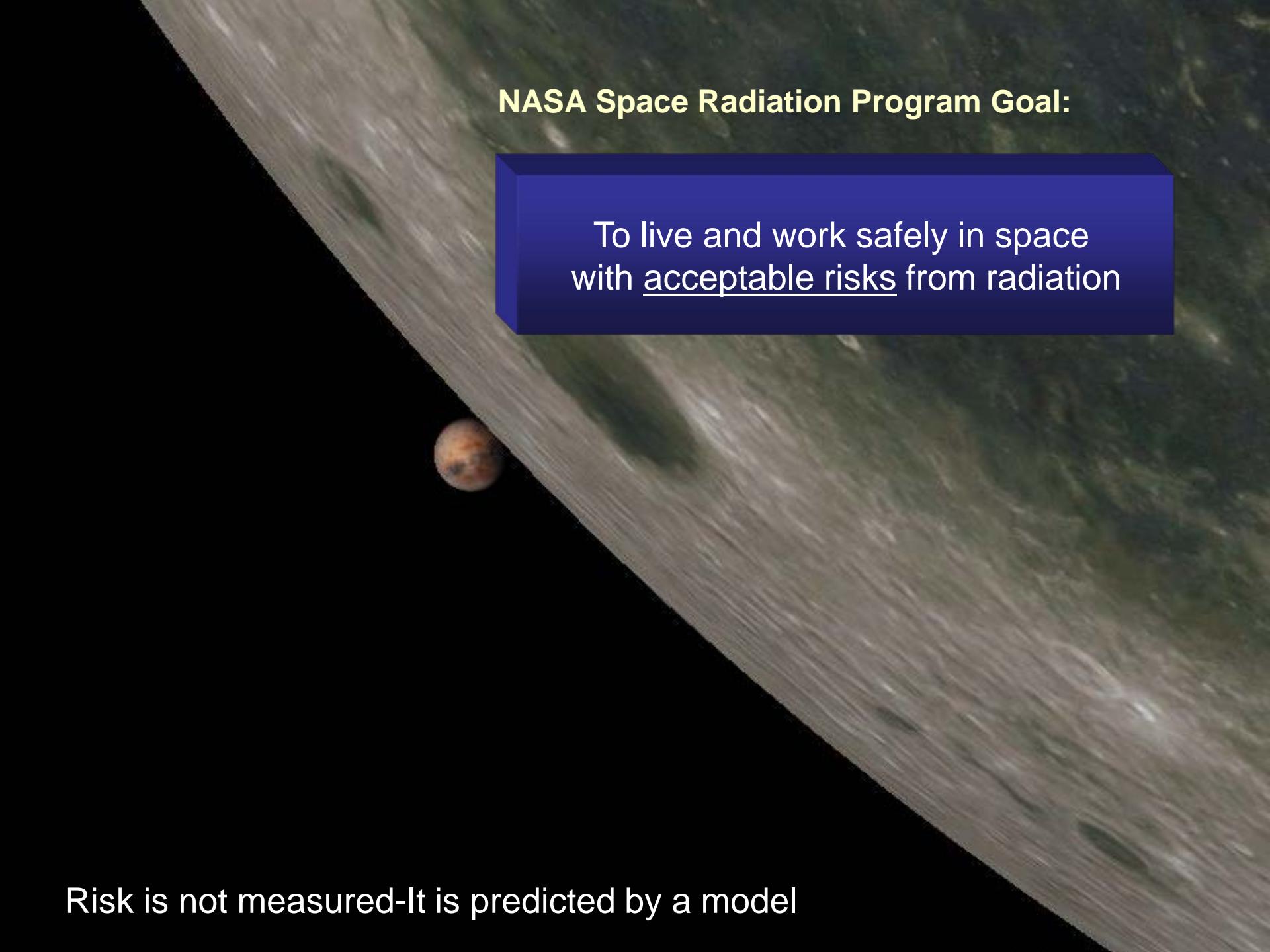
In space exploration outside the Earth's geomagnetic field, radiation exposure from solar particle events (SPE) presents a health concern for astronauts, that could impair their performance and result in possible failure of the mission. Acute risks are of special concern during extra-vehicular activities because of the rapid onset of SPE. However, most SPEs will not lead to acute risks but can lead to mission disruption if accurate projection methods are not available. Acute Radiation Sickness (ARS) is a group of clinical syndromes developing acutely (within several seconds to 3 days) after high dose whole-body or significant partial-body ionizing radiation exposures. The manifestation of these syndromes reflects the disturbance of physiological processes of various cellular groups damaged by radiation. Hematopoietic cells, skin, epithelium, intestine, and vascular endothelium are among the most sensitive tissues of human body to ionizing radiation. Most ARS symptoms are directly related to these tissues and other systems (nervous, endocrine, and cardiovascular, etc.) with coupled regulations. Here we report the progress in bio-mathematical models to describe the dose and time-dependent early human responses to ionizing radiation. The responses include lymphocyte depression, granulocyte modulation, fatigue and weakness syndrome, and upper gastrointestinal distress. The modest dose and dose-rates of SPEs are predicted to lead to large sparing of ARS, however detailed experimental data on a range of proton dose-rates for organ doses from 0.5 to 2 Gy is needed to validate the models. We also report on the ARRBOD code that integrates the BRYNTRN and SUMDOSE codes, which are used to estimate the SPE organ doses for astronauts under various space travel scenarios, with our models of ARS. The more recent effort is to provide easy web access to space radiation risk assessment using the ARRBOD code.

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NASA Space Radiation Program Goal:

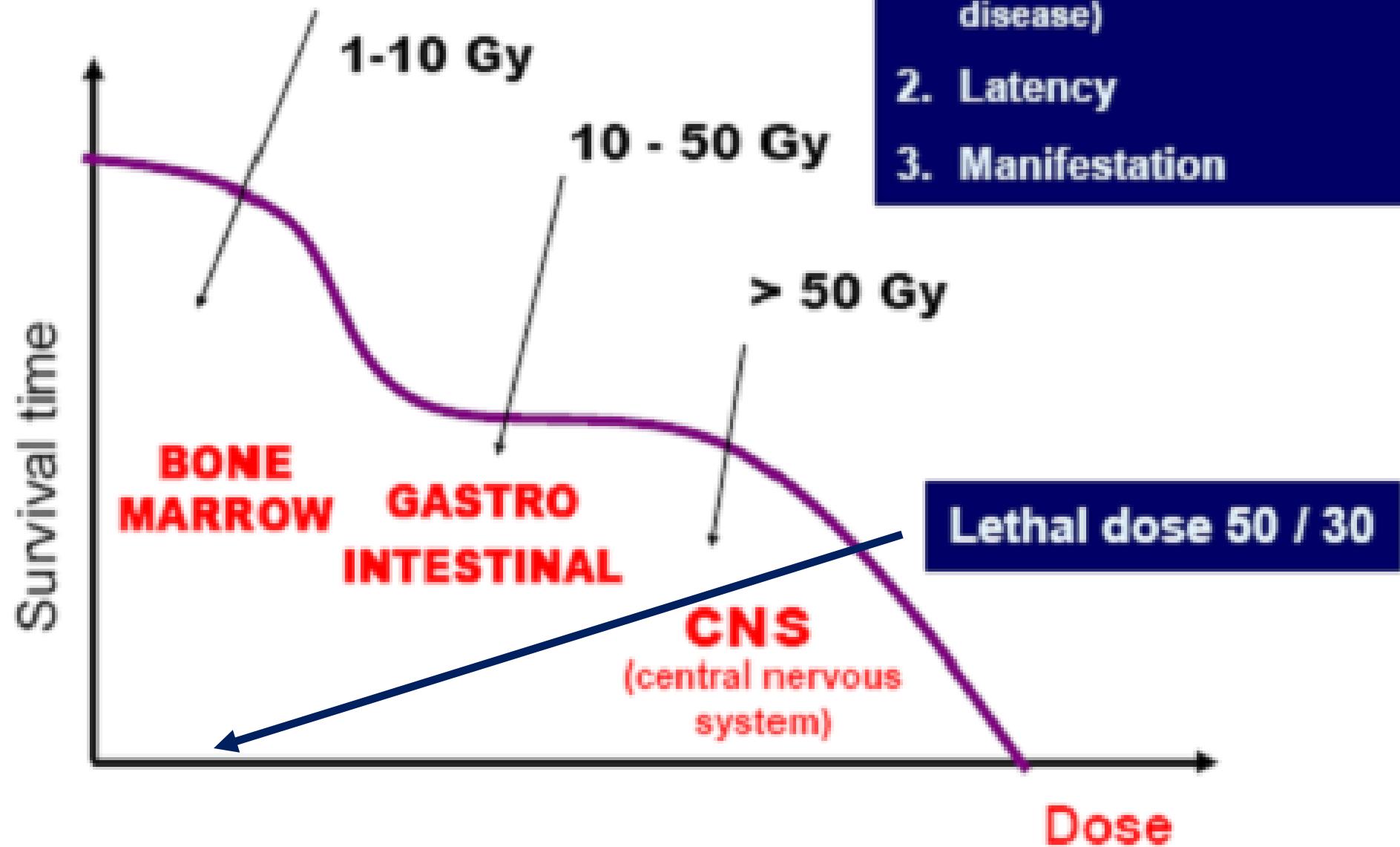
To live and work safely in space
with acceptable risks from radiation

Risk is not measured-It is predicted by a model

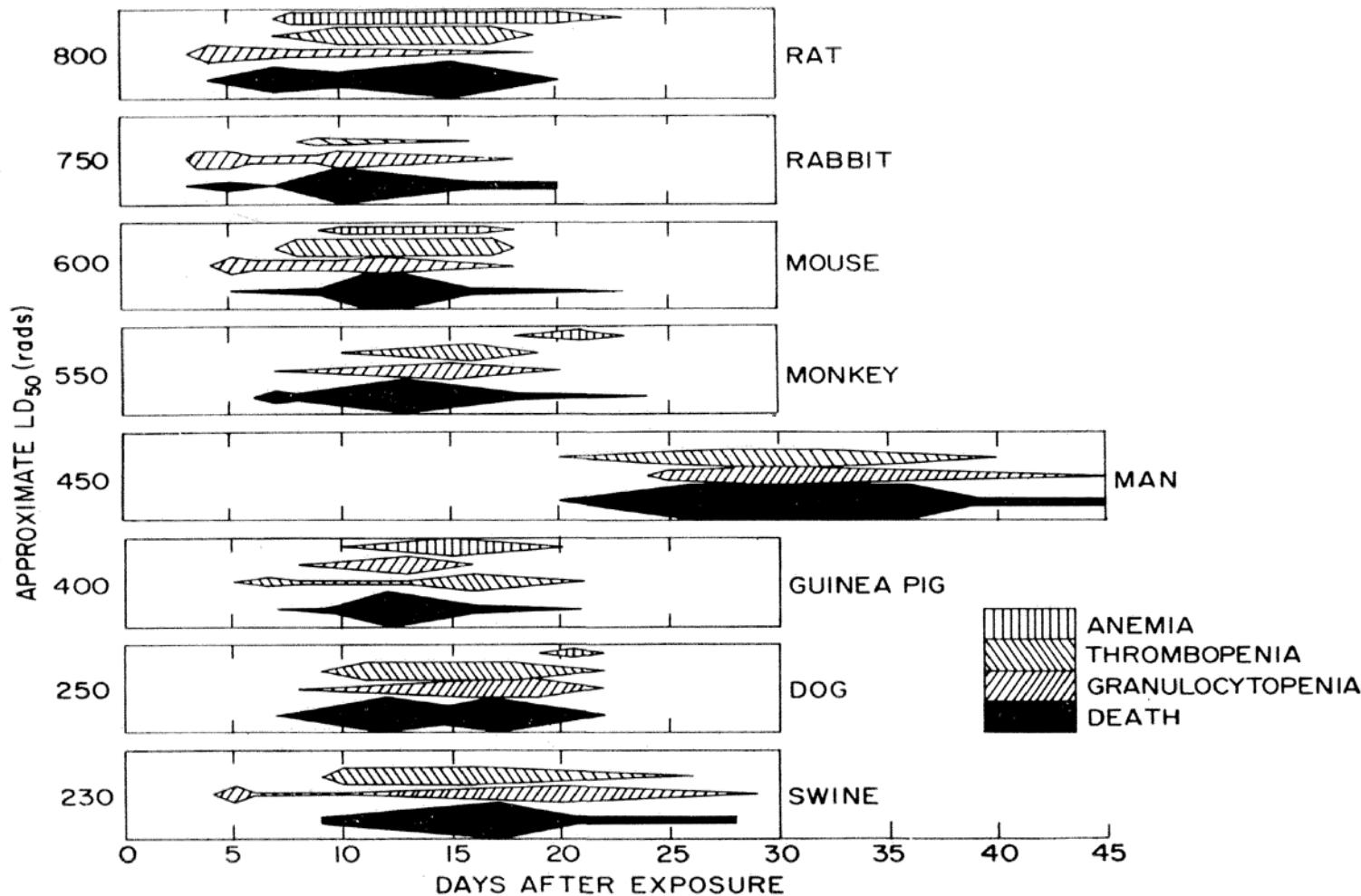
Acute irradiation syndrome

Steps:

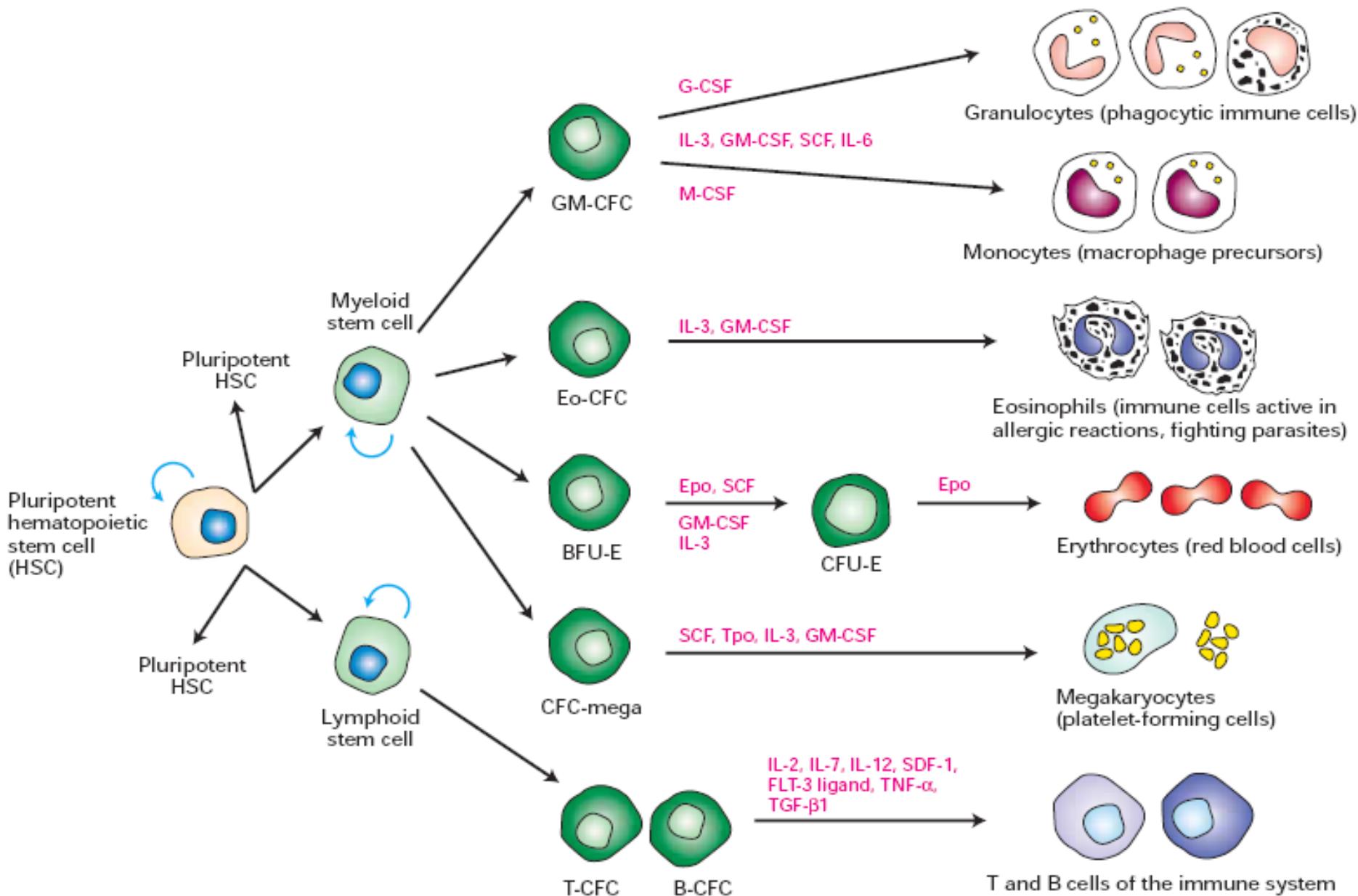
1. Prodromic (onset of disease)
2. Latency
3. Manifestation



Correlation of time of death with irradiation anemia of different species



Hematopoiesis in human



Basis of mathematical modeling: regulation mechanism

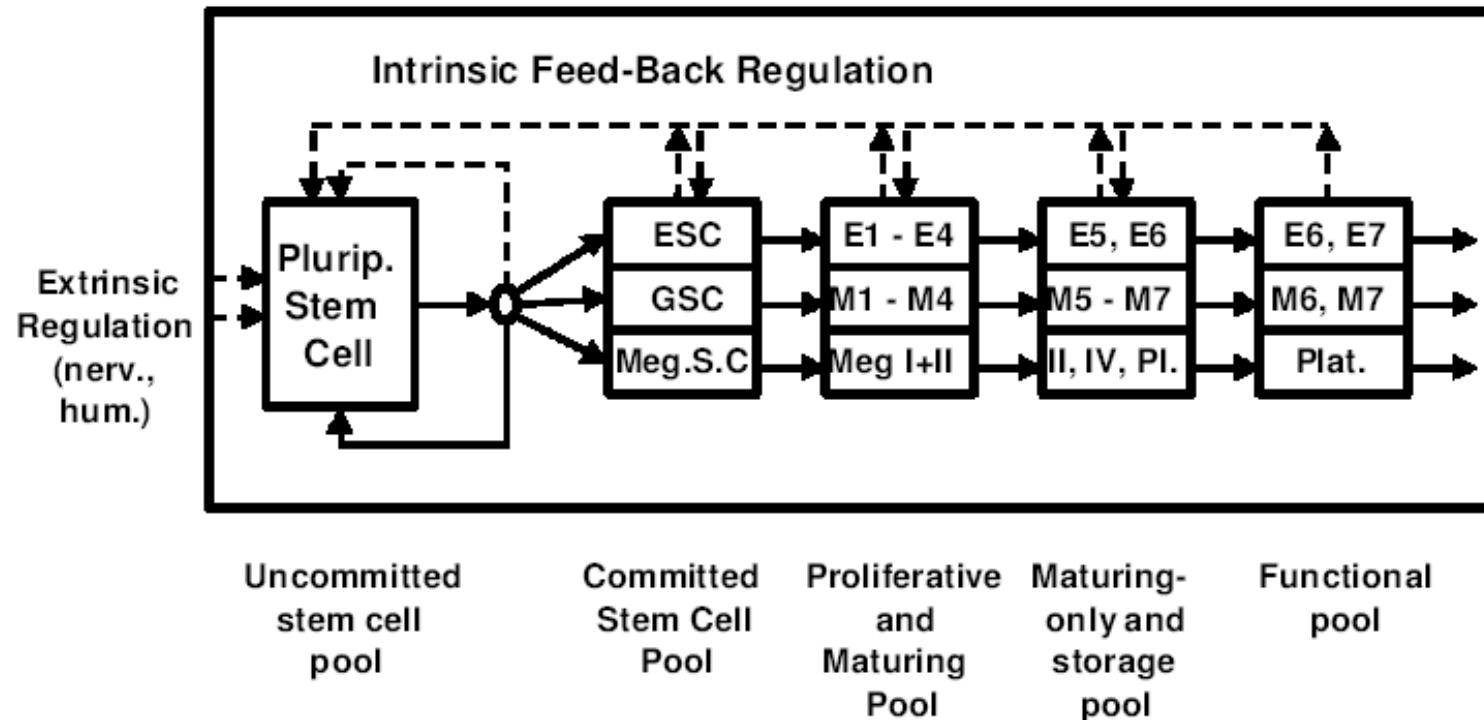


Figure 2. Schematic representation of the hemopoietic cell renewal systems (E = Erythropoiesis; G = Granulopoiesis; Meg = Megakaryocytopoiesis) all fed by the pluripotent hematopoietic stem cell pool.

Smirnova's model

- Three compartments:
 - X_1 : bone marrow precursor cells
 - X_2 : nondividing maturing bone marrow cells
 - X_3 : mature blood cells
- Feed-back regulator I : dependent on the concentration of X_1 , X_2 , and X_3 cells

Model equations:

$$\frac{dx_1}{dt} = Bx_1 - Cx_1,$$

$$\frac{dx_2}{dt} = Cx_1 - Fx_2,$$

$$\frac{dx_3}{dt} = Fx_2 - Ex_3,$$

$$\frac{dI}{dt} = G(x_1 + \theta_2 x_2 + \theta_3 x_3) - HI.$$

Granulocytopoiesis

$$\frac{dx_1}{dt} = \frac{\alpha x_1}{1 + \beta (x_1 + \theta_2 x_2 + \theta_4 x_4 + \theta_5 x_5)} - \gamma x_1,$$

$$\frac{dx_2}{dt} = \gamma x_1 - \delta \frac{1 + M x_4^2}{1 + L x_4^2} x_2,$$

Reserve pool in
bone marrow

$$\frac{dx_4}{dt} = \delta \frac{1 + M x_4^2}{1 + L x_4^2} x_2 - \kappa x_4,$$

$$\frac{dx_5}{dt} = \kappa x_4 - \psi x_5.$$

Tissue pool

Lymphopoiesis model

$$\frac{dx_1}{dt} = Bx_1 - \mathcal{K}_1 - \frac{N}{D_e}x_1,$$

$$\frac{dx_{wd1}}{dt} = \left(\frac{N}{D_e} - \frac{N}{D_1} \right) x_1 + Bx_{wd1} - \mathcal{K}_{wd1},$$

$$\frac{dx_{d1}}{dt} = \frac{N}{D_1} \frac{1}{1 + \rho_1} x_1 - \nu_1 x_{d1},$$

$$\frac{dx_{hd1}}{dt} = \frac{N}{D_1} \frac{\rho_1}{1 + \rho_1} x_1 - \nu_2 x_{hd1},$$

$$\frac{dx_2}{dt} = \mathcal{K}_1 - \delta x_2 - \frac{N}{D_2} x_2,$$

$$\frac{dx_{d2}}{dt} = \frac{N}{D_2} \frac{1}{1 + \rho_2} x_2 - \nu_1 x_{d2},$$

$$\frac{dx_{hd2}}{dt} = \frac{N}{D_2} \frac{\rho_2}{1 + \rho_2} x_1 - \nu_2 x_{hd2}$$

$$\frac{dx_3}{dt} = \delta x_2 - \psi x_3 - \frac{N}{D_3} x_3,$$

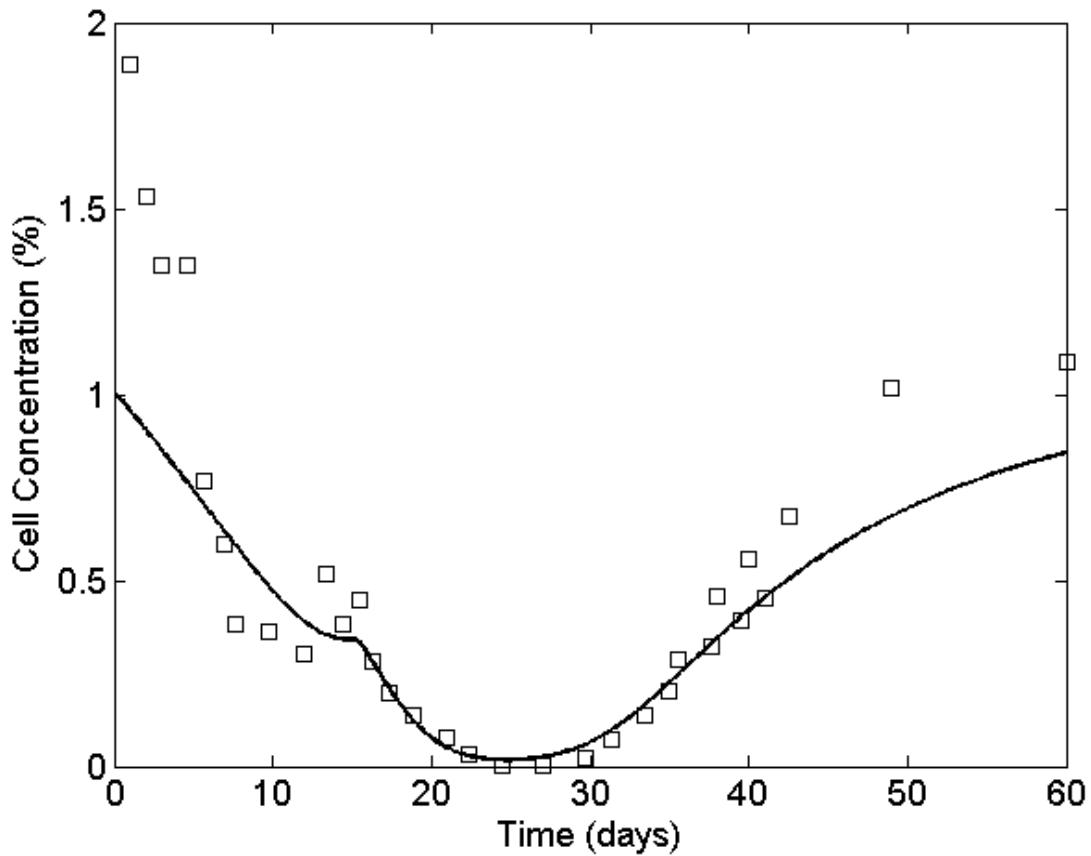
$$\frac{dx_{d3}}{dt} = \frac{N}{D_3} \frac{1}{1 + \rho_3} x_3 - \nu_1 x_{d3},$$

$$\frac{dx_{hd3}}{dt} = \frac{N}{D_3} \frac{\rho_3}{1 + \rho_3} x_3 - \nu_2 x_{hd3}$$

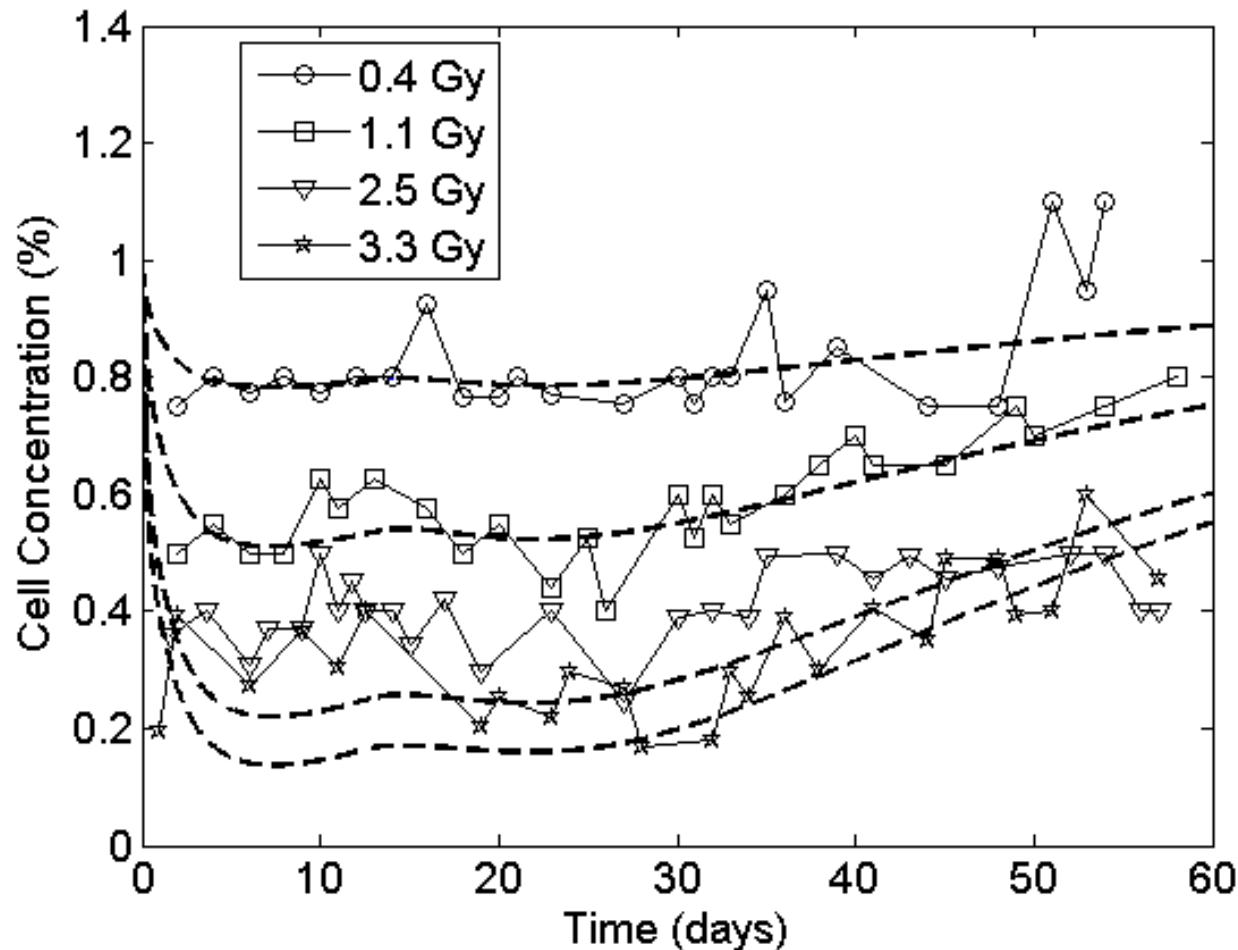
Acute irradiation of human: data of 11 Chernobyl patients and model simulation

Exposure range from 2.6 to 7.1 Sv.

Assuming an average 5.9 Sv exposure.



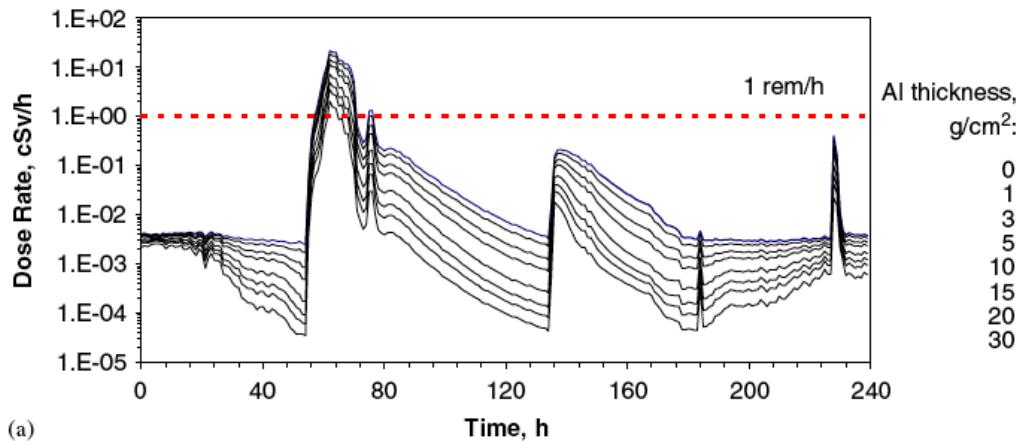
Chernobyl accident



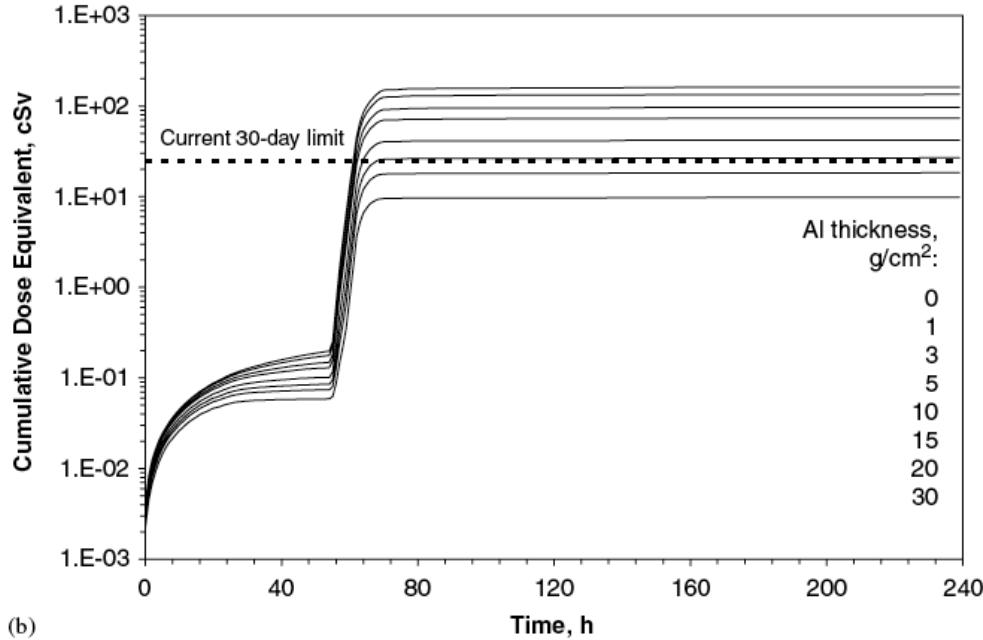
Guskova et al, 2001

Radiation Exposure from Large SPE Events

BFO dose rate
during Aug.
1972 SPE
Event

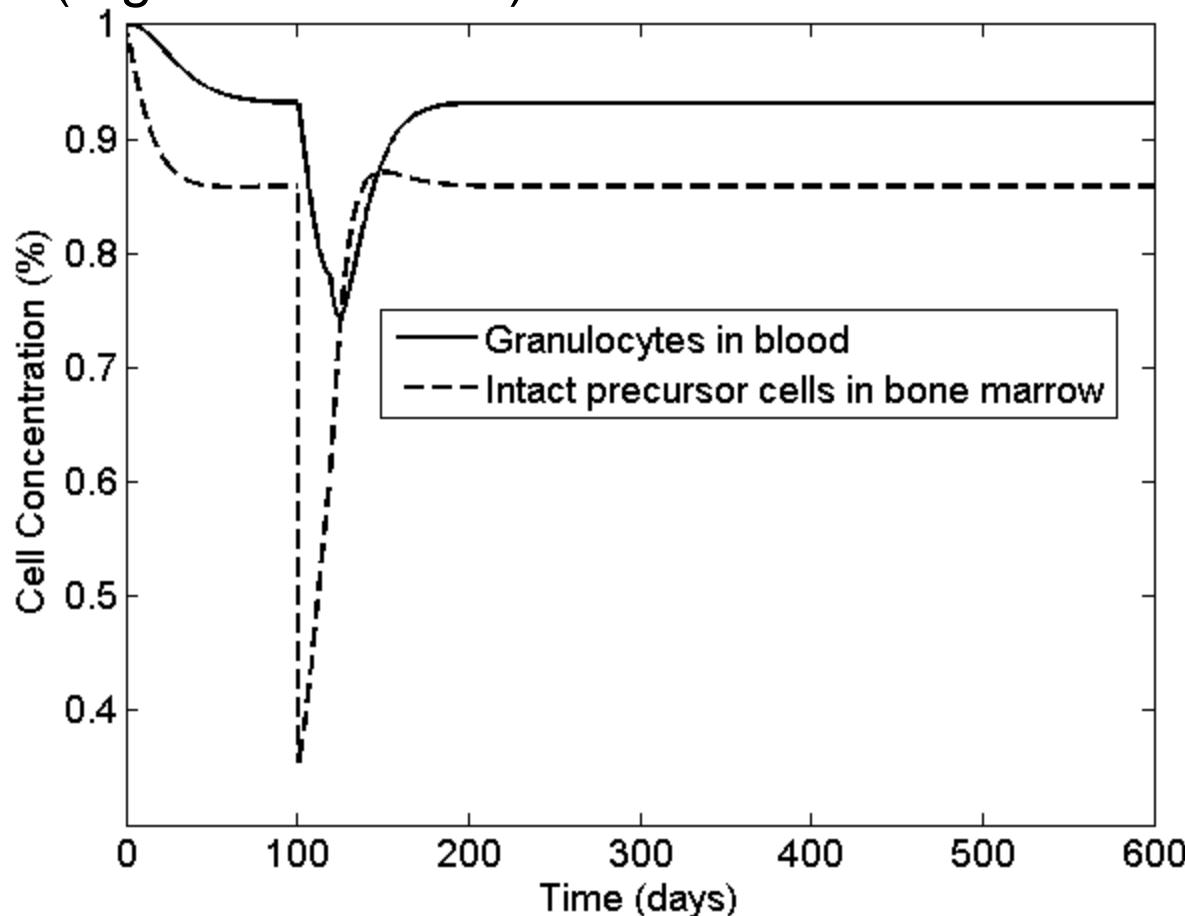


Cumulative
dose



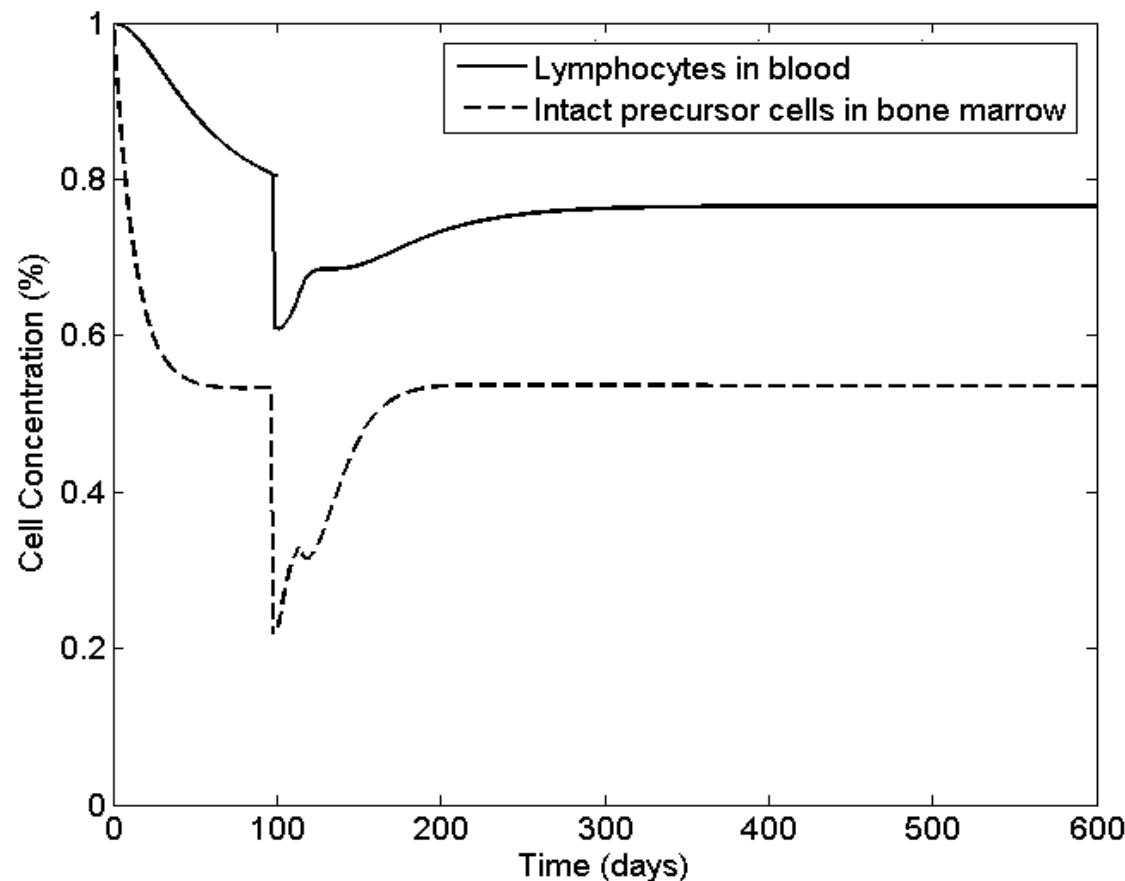
Modeling the granulopoiesis response to the 1972 SPE

Recorded worst SPE: 44.3 mSv/h for 10 hours inside a typical spacecraft (5 g/cm thickness) .

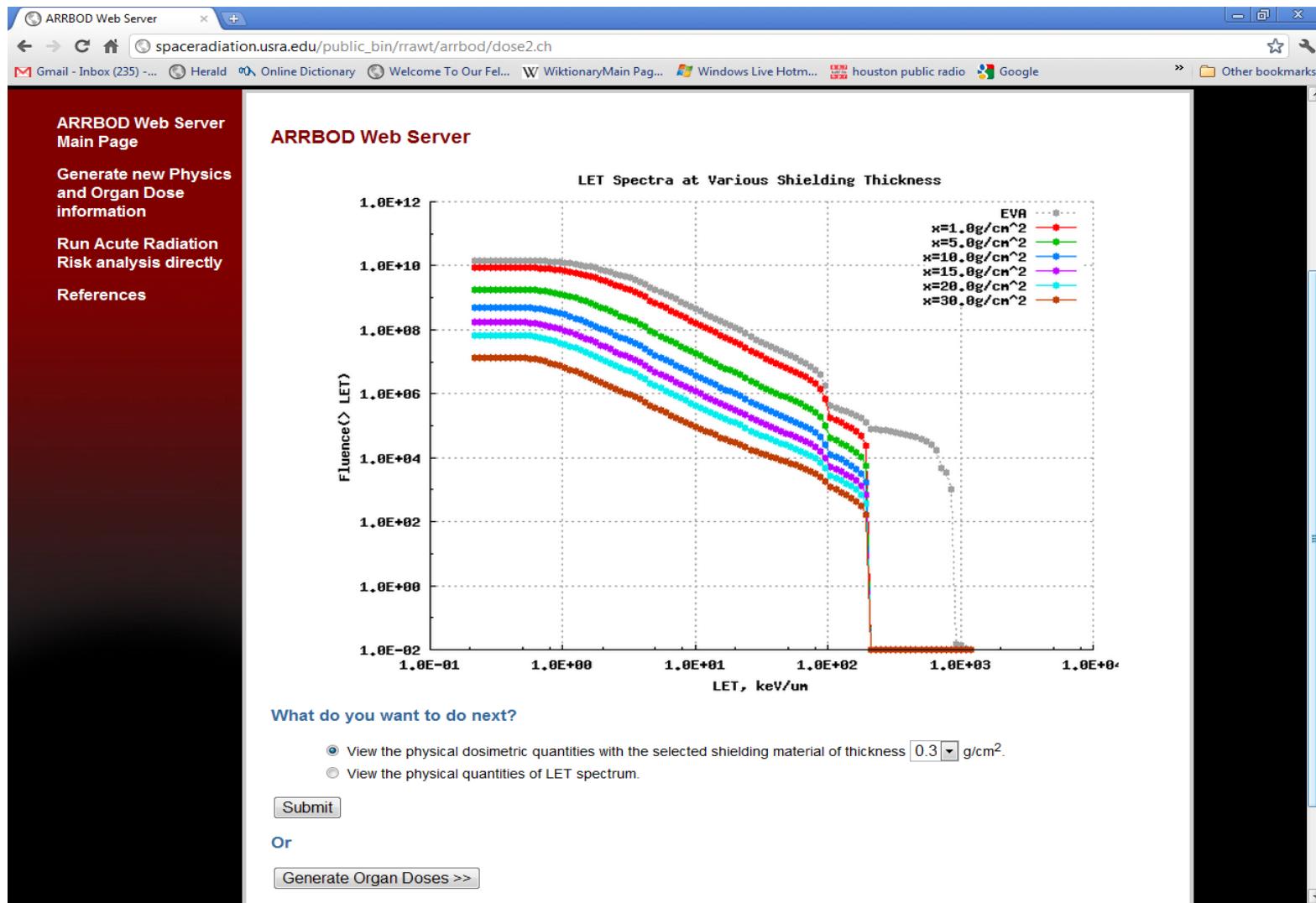


Modeling the lymphopoiesis response to the 1972 SPE

Recorded worst SPE: 44.3 mSv/h for 10 hours inside a typical spacecraft (5 g/cm thickness) .



ARRBOD Web Server



<http://spaceradiation.usra.edu/irModels>

It is not ready for public use yet.



ARRBOD Web Server

spaceradiation.usra.edu/rrawt/rrawt1.html

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ARR Web Tools Main Page

Lymphocytes Depression

Granulocytes Modulation

Fatigue and Weakness Syndrome

Upper Gastrointestinal Distress

References

Acute Radiation Risk Assessment Web Tools

Acute Radiation Sickness (ARS) is a group of clinical syndromes developing acutely (within several seconds to 3 days) after high dose, whole-body or significant partial-body ionizing radiation. The manifestation of these syndromes reflects the disturbance of physiological processes of various cellular groups damaged by radiation. Hematopoietic cells, skin, epithelium, intestine, and vascular endothelium are among the most sensitive tissues of human body to ionizing radiation. Most ARS syndromes are directly related to these tissues, as well as the coupled regulation and adaptation systems (nervous, endocrine, cardiovascular systems). There are three phases in the development of ARS: the prodromal phase, the latent phase, and the manifest phase. The severity and duration of each of these phases are dependent on the dose and dose rate. The prodromal phase refers to the first 48 hours after exposure, but may persist up to 6 days. The syndromes are dose-dependent and include hematopoietic depression, gastrointestinal distress (nausea, vomiting and/or diarrhea), and neurological symptoms (including fatigability, weakness, headache, impaired cognition, disorientation, ataxia, seizures and hypotension). The latent phase lasts about 2 to 20 days with a seeming improvement of most syndromes (except cytopenia), with duration correlating inversely with the absorbed dose. The manifest phase lasts from 2 to 60 days, with signs and symptoms expressed by various organs, and profound immune suppression predisposing the body to infection and sepsis. This phase is critical for radiation injury. Most patients surviving this phase will recover, but are still at risk for intermediate effects such as pneumonitis and late effects.

We have developed/adapted four biomathematical models to quantitatively characterize the degrees of ARS under various radiation conditions. The two hematopoietic models can also be used as tools to estimate the exposed dose or dose rate based on the depressed level of cells in peripheral blood.

- [Lymphocytes Depression](#)
- [Granulocytes Modulation](#)
- [Fatigue and Weakness Syndrome](#)
- [Upper Gastrointestinal Distress](#)

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